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PATH PLANNING FOR MOBILE ROBOTS NAVIGATION WITH OBSTACLE AVOIDANCE BASED ON OCTREES

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ПЛАНУВАННЯ ШЛЯХУ ДЛЯ НАВІГАЦІЇ МОБІЛЬНИХ РОБОТІВ З УНИКНЕННЯМ ПЕРЕШКОД НА ОСНОВІ ДЕРЕВА ОКТАНТІВ

Abstract. The article considers the problem of navigating mobile robots and finding the best way to the goal in real-time in a space surrounded by unknown objects. The motor actions of the robot must be defined and adapted to changes in the environment. When using only laser scanners on mobile work, objects above or below the lasers' level will remain obstacles to the robot. Current algorithms and principles of navigation are considered. Extended the existing real-time interference detection system using lasers by adding a camera that calculates the length of objects. The new system has been successfully implemented and tested in a mobile robot, ensuring the passage of the road providing collision-free paths. The obtained simulation results are presented in the article. The existing problems of navigation of mobile robots, which are moving in the particular area from their position to the specified destination on the map, were investigated. The current problem is the inability to spot objects that are not on the same level as the mobile robot's lasers. Moreover, the task is complicated when you need to recognize such objects while the robot is moving in real time. The current algorithms and principles of navigation given by previous research and publications are analyzed. As a result of the work, the existing system of recognition and avoidance of obstacles was expanded. Prior to that, the system used only odometry and information obtained from laser scanners, without obtaining data from other sources of environmental information. The idea of development was to use a camera, which was already part of the components of the researched mobile robot. It has become possible to generate a pointcloud relative to the environment, using a depth-sensing camera to calculate the distance to objects. Because the density of the received data in the form of a pointcloud is too high for further processing, a downsample VoxelGrid filter was used, which reduces the density of the point cloud. VoxelGrid belongs to the PCL library. Another problem was the removal of information about unnecessary objects in the camera's field of view. These include the floor, ceiling, parts of the robot (such as a manipulator). The PassThrough filter from the PCL library was used to solve this problem. The next step is to process the filtered data using OctoMap. As a result, an octree is generated. A top-down projection is created from the octree generated in the previous step. The resulting projection must be processed and converted into polygonal obstacles. Only then they will be marked by teb_local_planner as obstacles. The developed system was successfully implemented and tested both in the Gazebo simulation and in the researche mobile robot. The path with obstacles will be completed without collisions. The paper presents the obtained test results.
Keywords: ROS; navigation; mobile robots; obstacle avoidance; octree; laser; point cloud.

Анотація. У роботі розглядається проблема навігації мобільних роботів та знаходження найоптимальнішого шляху до цілі в реальному часі на площині в оточенні невідомо розташованих об’єктів. Рухові дії робота повинні визначатися та адаптуватися до змін навколишнього середовища. При використанні тільки лазерних сканерів на мобільному роботі, об'єкти, які знаходяться вище чи нижче рівня лазерів, будуть залишатися перешкодами для робота. Розглянуто актуальні алгоритми та принципи навігації. Розширено існуючу систему розпізнавання перешкод у реальному часі з використанням лазерів шляхом додавання камери, яка розраховує довжину до об’єктів. Нова система була успішно реалізована та випробувана на мобільному роботі, забезпечуючи проходження шляху без зіткнень. Отримані результати моделювання представлені в роботі. Було досліджено існуючі проблеми навігації мобільних роботів, які рухаються на поверхні від свого положення до зазначеної мети на карті. Актуальною проблемою є неможливість помічати об’єкти, які розташовані не на одному рівні з рівнем лазерів мобільного робота. Більш того, завдання ускладнюється, коли потрібно розпізнавати такі об’єкти під час руху робота в реальному часі. Проаналізовано актуальні алгоритми та принципи навігації, приведені в минулих дослідженнях та публікаціях. У результаті роботи було розширено існуючу систему розпізнавання та обходження перешкод. До цього система використовувала лише одометрію та інформацію, отриману з ла-

зерних сканерів, не отримуючи даних з інших джерел інформації про навколишнє середовище. Ідеєю розробки стало використання камери, яка вже входила до складу компонентів досліджуваного мобільного робота. Із використанням камери, що сприймає глибину, розраховуючи відстань до об'єктів, стало можливим генерувати хмару точок відносно навколишнього середовища. Оскільки щільність отримуваних даних у вигляді хмари точок є завеликою для подальшої обробки, було використано downsample фільтр VoxelGrid, що зменшує щільність хмари точок. VoxelGrid відноситься до бібліотеки PCL. Подальшою проблемою було видалення інформації щодо зайвих об'єктів у полі зору камери. До них можна віднести підлогу, стелю, частини робота (такі, як маніпулятор). Для вирішення цієї проблеми було використано PassThrough фільтр із бібліотеки PCL. Наступним кроком є обробка відфільтрованих даних за допомогою OctoMap. У результаті чого генерується дерево октантів. Із дерева октантів, згенерованого в попередньому етапі, створюється проєкція в напрямку зверху вниз. Отримана проєкція повинна бути оброблена та перетворена в полігональні перешкоди. Тільки в цьому випадку вони будуть помічені teb_local_planner як перешкоди. Розроблена система була успішно реалізована та випробувана як у симуляції Gazebo, так і на досліджуваному мобільному роботі. Проходження шляху з перешкодами буде виконано без зіткнень. У роботі наведені отримані результати випробування.

Ключові слова: ROS; навігація; мобільні роботи; уникнення перешкод; дерево октантів; лазер; хмара точок.

Introduction

Mobile robotic systems are used today in a wide variety of industries. The wider the scope of their application, the more stringent the requirements for their performance for specific tasks become. One of the most urgent such requirements relates to the autonomy of the robot and its navigation capabilities [1].

Navigation remains the main problem of all currently existing mobile devices moving independently. For successful navigation in space, the on-board system of the robot must be able to plan a path, as a strategy to find a path towards a goal location, correctly interpret information about the world around it received from the sensors. Moreover, the robot should control movement parameters, its own coordinates, and be able to adapt to environmental changes.

Robotics develops more and more every year. New approaches are being created to solve the problems of motion, localization, and automation of robots. Many models have made great strides in solving various problems. A lot of technical complexes are created for military purposes: target detection, its elimination. Robot firefighters are being created; rescue robots capable of getting people out of the water, from the rubble of collapsed buildings.

One of the many trends in robotics is the transition from remote-controlled systems, which require constant human participation to perform all the robot's actions, to autonomous systems in which the operator only indicates the final and intermediate goals. This is convenient for carrying out alien research, where a large signal delay does not allow remote control [2].

Problem Statement

One of the most challenging aspects of autonomous outdoor mobile robot navigation is reliability. That is, a mobile robot must be able to reach its destination safely, every single time, not only avoiding collisions to obstacles and humans around it, but also successfully driving through difficult paths such as slopes, bumps, or potholes.

Mobile robots should be equipped with different sensors that will transmit data about the environment. When using only laser scanners on mobile work, objects above or below the lasers' level will remain obstacles to the robot. Obstacles above or down the level of the laser scanner cannot be recognized. Thus, the route is built incorrectly. Consequently, the robot encounters obstacles.

Analysis of recent research and publications

After analyzing modern work in the field of mobile robot navigation and avoiding obstacles in real-time, it was found that in contemporary control theory, research in robotics, the most promising areas of development are the use of algorithms based on data processing from sensors.

The authors of [3] focus on the internal system of localization of the robot on the basis of ultrasound. The proposed solution is to measure the position of robots calculated using triangulation formulas.

The algorithm developed in [4] allows determining the position of robots at any

time, using the position of landmarks. The algorithm takes into account asynchronous time steps and disparate measurement data to develop its estimates.

One of the simplest means of movement on the specified route is odometry, which is based on establishing the route of movement of the robot by determining the movement of the robot wheels [5]. The strong disadvantage of this technique is the accumulation of error during movement, so it is advisable to use it with other means of navigation, to correct this error [6].

The aim of the research

The aim of the research is to create a real-time obstacle recognition and avoidance system, using sensors to ensure the road of the path without collisions with objects that are not on the same level as the lasers.

The goal is to explore recent studies about the 2D obstacle avoidance for a mobile robot. Develop an improved method for obstacle detection in a dynamic environment, plan the route for a mobile robot with avoidance of detected obstacles. The developed solution should take pointcloud as input data.

The algorithm is based on processing pointcloud data to an octree, building projection, and converting it to obstacles.

2D navigation in ROS

There two types of mobile robot navigation: 2D and 3D. 3D is applicable for flying robots when the topic of this research is 2D navigation. The robot, the subject of the research, only able to move with wheels in 2D space.

ROS itself provides an implementation of several 2D navigation approaches called 2D navigation stack. The stack takes information from sensors, odometry, and goal pose and gives velocity commands to move the mobile base safely. As a pre-requisite for navigation stack use, the robot must be running ROS, have a tf transform tree in place, and publish sensor data using the correct ROS Message types. Also, the Navigation Stack needs to be configured for a robot's shape and dynamics to perform at a high level.

Action`s implementation is provided in the move_base package. The given goal in the world needs to be reached with a mobile base. A global and local planner are linked together by the move_base node to accomplish its global navigation task. In the nav_core package nav_core::BaseGlobalPlanner interface is specified and global planner is adhesive to it. The same situation with any local planner. Any local planner adhering to the nav_core::BaseLocalPlanner interface from the nav_core package.

The node maintains two costmaps, from the global and local planners, which are used to accomplish navigation tasks.

Timed Elastic Band optimizes the robot`s trajectory with an execution time locally, separation from obstacles, and compliance with kinodynamic constraints at runtime. The teb_local_planner package performs a plugin to the base_local_planner of the 2D navigation stack.

An online optimal local trajectory planner for mobile robot`s control and navigation is implemented by this package as a plugin for the navigation package in ROS.

The original trajectory, which is generated by a global planner, is optimized during runtime. As a result, trajectories` execution time minimizing, separation from obstacles, compliance with kinodynamic constraints like satisfying maximum accelerations and velocities.

The current implementation complies with the kinematics of non-holonomic robots such as differential drive and car-like robots. Support of holonomic robots is included since Kinetic.

Types of sensors

There are several types of sensors. The investigated robot has two types of sensors: planar laser scanners and depth cameras.

Laser SICK S300 is used as the main environment scanner for navigation. It is a laser scanner with a scanning angle 270 and angular resolution 0.5.

The other type of sensor is a depth camera. The depth camera is represented by the Intel Realsense D435 camera. Using a dual camera rig provides a depth image that can be

converted to pointcloud. This conversion is done by ROS Realsense camera node. When the camera is set up appropriately in the robot description in the same place as in the real world, the node will provide pointcloud data relative to the robot. If the robot is well positioned, the data will be relative to the world as well.

The density of the provided raw point cloud is too big. It can be safely downsampled to dramatically less density. It is done with the VoxelGrid filter provided by PCL.

PCL also provides another very useful filter named PassThrough which is used to cut too low and too high data (floor and ceiling) which should not be treated as an obstacle. And we cut too close objects which are parts of the robot itself, usually, it is arm appears in camera sight.

SLAM

SLAM – simultaneous localization and mapping, is an approach to process multiple frames and sensor positions to build a volumetric model of the environment.

Visual slam can be performed even with a single camera (monocular) setup. It is cheap and straightforward. Depth is not fully available from one image; instead, we need multiple images to match them and compute a disparity.

With two cameras, it is even easier – we have a fixed distance between cameras

Having the disparity, we can set a distance from the camera for each point and, based on it, build a 3D representation of an image for the current frame.

The whole SLAM approach implies building a full map. SLAM can use multiple different types of sensors, and the powers and limits of various types of sensors have been a significant driver of new algorithms. Statistical independence is required to cope with metric bias and noise in measurements. Data from different types of sensors can be processed by different SLAM algorithms whose approaches are more compatible with the sensors. Laser scanners or visual features provide details of many points within an area, sometimes rendering SLAM inference is unnecessary because shapes in these point clouds can be quickly and unambiguously aligned at each step via image registration. At the opposite extreme, tactile sensors are too sparse as they contain only information about points very close to the agent. Hence, they require strong models to compensate in pure tactile SLAM. Most applicable SLAM tasks are somewhere between these visual and tactile areas.

We can use odometry, GPS, and localization based on joint angles for localization, based on camera images.

Octree with OctoMap

An octree is a tree in which each vertex has eight children. Octal trees are most often used to divide three-dimensional space by recursive partitioning into octants. Octrees are hierarchical tree structures that describe each region of 3D space as nodes.

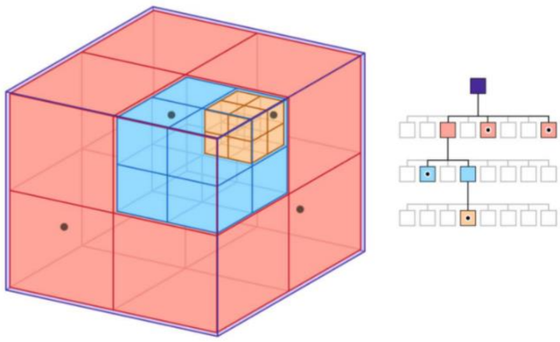

Fig. 1. Octree on sample data

Usually, octrees are widely used in computer science. They have generic data structures that is why they are an appropriate way of storing information in an area on unparameterized meshes.

The OctoMap library implements a 3D occupancy grid mapping approach, providing data structures and mapping algorithms. The map implementation is based on an octree. This model data can then be used for navigation and obstacle avoidance.

OctoMap provides converting point cloud data to occupancy grid octree. Then these occupied octants(voxels) are projected to the floor providing an image of the occupied area.

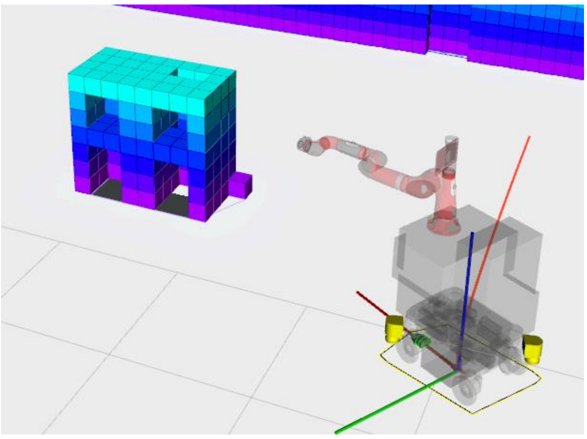

Fig. 2. Octree based on a recognized object

Projection to obstacles

But projection itself is not an obstacle for the navigation stack. The most appropriate input with obstacles for the navigation stack is an obstacle topic teb_local_planner subscribed on. It can consume obstacles as point obstacles or polygons.

Firstly, direct conversion from occupied pixels to point obstacles were developed. This solution does not provide needed path planning because teb_local_planner tries to build the route through the obstacle between close points where is not enough space to go.

The better way is to build polygons around the occupied areas on the projection.

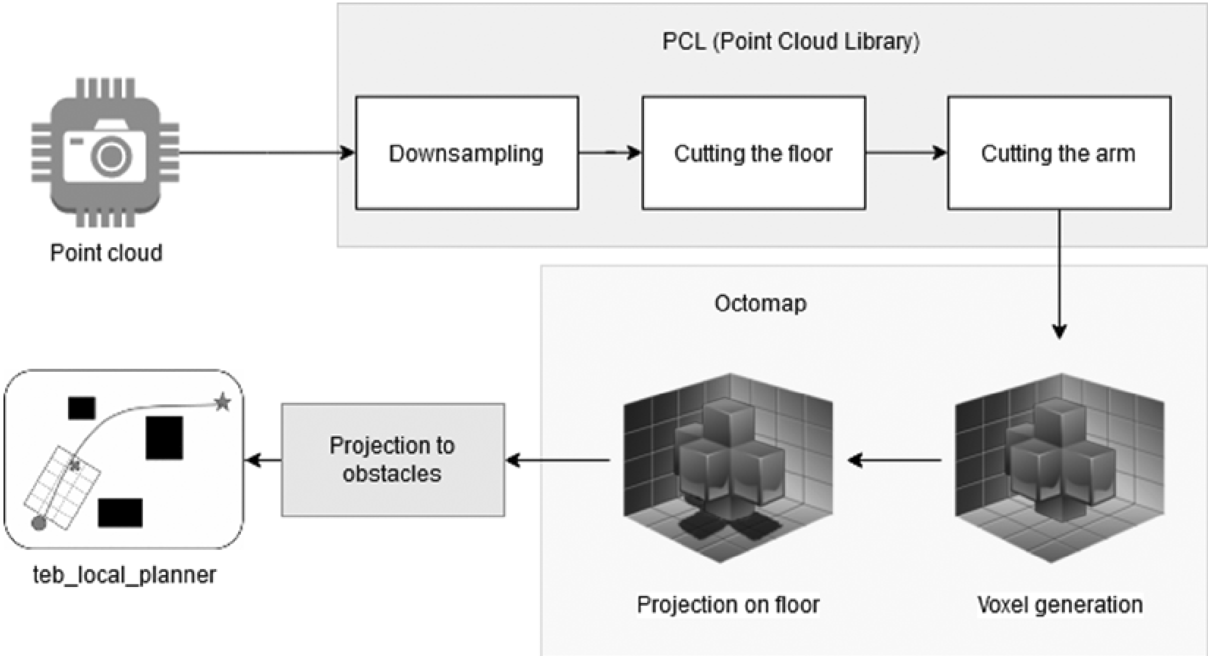

Fig. 3. Octree navigation pipeline

In this case, there no small space inside the occupied area, and the path is built appropriately around the obstacle.

In this manner, the mobile robot will be able to recognize and to avoid the obstacle, which was found on the way from the starting point to the goal. The mobile robot will change the route, which was built, accordingly to the obstacle, which was found.

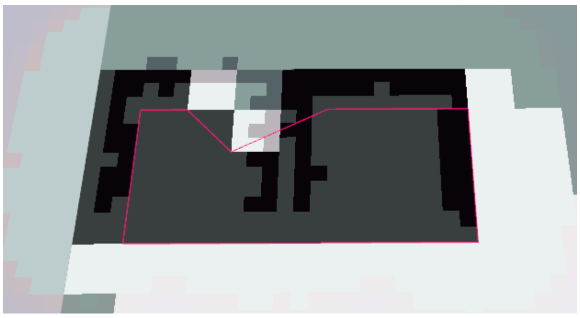

Fig. 4. Projection converted into polygon obstacle

Conclusions

The result of the work presented above was the development of a new system for recognizing objects in the path of the robot, which is not at the same level as the mobile robot`s lasers. The paper discusses various methods and algorithms for navigation that exist. The stages of the research and the obtained results are also described. As a result of using a new system using a Realsense camera, it was found that such a system is better and more efficient than using only lasers.

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